APPENDIX B: CABLE COUPLING

Electromagnetic fields incident on a shielded cable will excite currents on the cable. The current excitation will depend on the polarization of the fields with respect to the cable and the strength of the fields. These external currents will then excite voltages internal to the cable. These internal voltages will appear at sensitive electronics as an undesired signal. Damage is possible if the voltage strength is large.

Cable coupling is most easily analyzed in the spectral domain. The time domain response can be found by multiplying the spectral domain response of the cable with the spectral domain representation of the excitation field (the pulsed RF) and then transforming back to the time domain. In the spectral domain (*s*-domain, s = jw) the per-unit-length (along the cable direction – here defined as the z-axis) voltages (V) and currents (I) induced inside the cable shield are related to the total (exterior plus interior) current (I_T) and per-unit-length total charge (Q_T) on the cables by

$$\begin{aligned} &V(z,s) = Z_t(s) I_T(s,z) \\ &I(z,s) = \Omega_t(s) Q_T(s,z) \\ &\frac{dI_T(z,s)}{dz} + sQ_T(z,s) = 0 \end{aligned} \qquad \text{(B1)}$$

where Z_t is the transfer impedance per-unit-length and W_t is the charge transfer frequency [8]. The transfer impedance relates the current induced on the cable exterior to the voltage induced within the cable and thus is a key parameter. Low transfer impedance indicates a well shielded cable. The currents and charges induced on the cable exterior will depend on the cable geometry, the presence of ground planes and other nearby conductors (the cable may be routed along a tower leg), and the polarization of the incident field. The time domain response can be found by multiplying the spectral domain response of the cable with the spectral domain representation of the excitation field (the pulsed RF) and then transforming back to the time domain. Two typical cable types, tubular and braided, will be considered next.

B1. Tubular Cable

For a tubular cable shield with conductivity s, and inner and outer radii b and c respectively (shield thickness $d = c-b$), assuming $d/b << 1$ and $d/c << 1$ (thin wall), the transfer impedance and charge transfer frequency are given by

$$\begin{aligned} &Z_t(s) \approx R_{dc} \frac{gd}{\sinh gd} \\ &R_{dc} = \frac{1}{2ps\ d\sqrt{bc}} \quad , \\ &g = \sqrt{sm_0 s} \end{aligned} \qquad \text{(B2)}$$

where R_{dc} is the dc shield resistance, $\Omega_t = 0$, and m_0 is the free space permeability. As the shield material approaches that of a perfect conductor ($s \rightarrow \infty$) the transfer impedance goes to zero, $Z_t \rightarrow 0$, implying zero internal induced voltage. Thus a good metallic shield will protect against high frequency RF coupling.

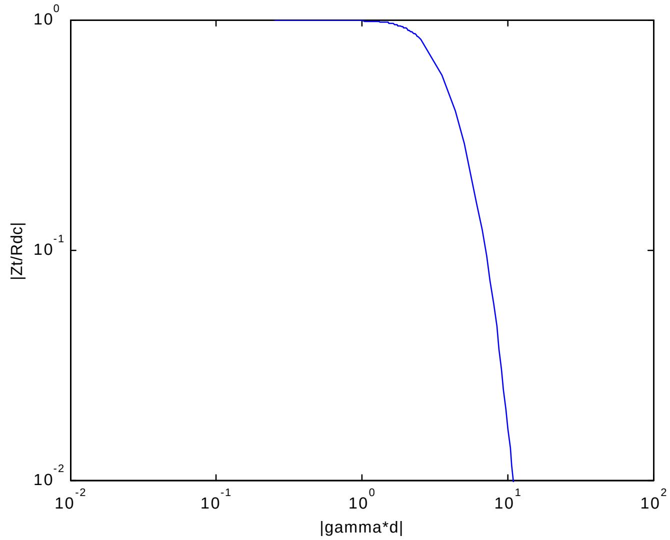

Figure B1. Magnitude of the normalized transfer impedance $Z_t(s)/R_{dc}$ versus gd (gamma*d) for a tubular cable.

Figure B1 shows the transfer impedance normalized to its dc value for a range of skin depth to wall thickness ratios (equivalent to gd). As an example, assume a metal tube with conductivity $s = 10^7$ (S/m) and wall thickness $d = 1$ (mm), and let the frequency f = 1 GHz. These values yield $\left| gd \approx 2.8(10)^2 \right|$ which is well above the range shown in the graph and yields a normalized transfer impedance on the order of $(10)^{-83}$. Thus, tubular coaxial cables should provide high levels of shielding for RF device frequencies. It is not expected that a solid tubular shield itself will allow any significant voltages to appear internally. However, coupling could still occur at connection points.

B2. Braided Cable

A braided cable is depicted in Figure B2. Useful approximations for the braided cable transfer quantities are given by [8] as

$$
\begin{aligned}
Z_t(s) &\approx \frac{1}{2ps\, bdK} \frac{gd}{\sinh gd} + s\frac{m_0}{2N} g[(1-K)^{3/2}, y\,] \\
\Omega_t(s) &\approx \frac{-ps}{N \ln(b/a)} h[(1-K)^{3/2}\, f_d, y\,]
\end{aligned}
\tag{3}
$$

$$f_d = \frac{2e_d}{e_d + e_j}$$

where K is the optical coverage of the braid, N is the number of carriers (bands of shield wires) in the braid, a and b are the inner and outer radii of the cable, d is the braid thickness typically taken as the diameter of the braid wire, y is the pitch angle of the woven braid (see Fig. B2), g and h are functions of the braid geometry, and e_d and e_j are the relative dielectric constants of the internal cable dielectric and the jacket respectively. Tables B1 and B2 give g and h for some typical parameters.

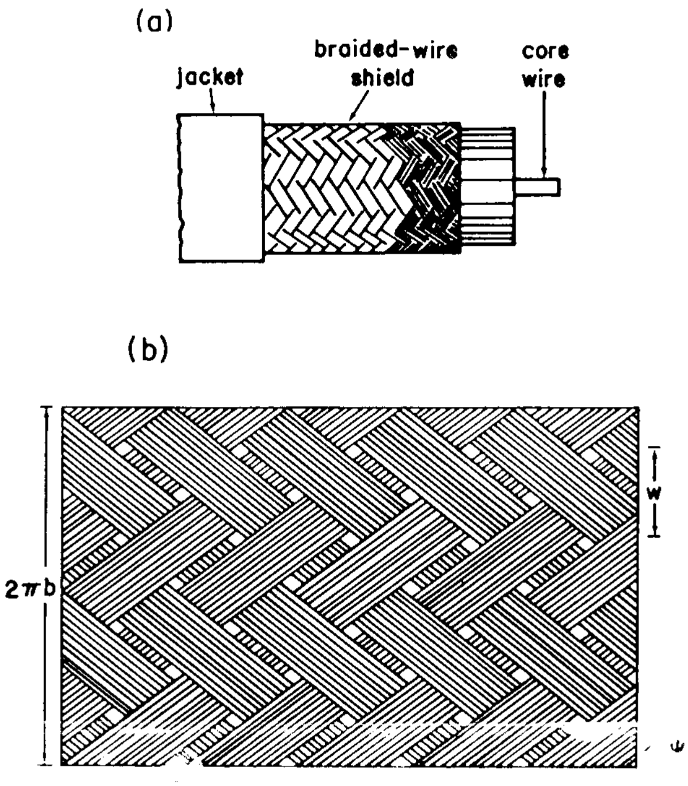

Figure B2. A braided shield (a) and its surface (b).

As an example consider standard RG8 cable with the following parameters: a = 1 mm, b = 5 mm, d = 0.73 mm, e_d = 3, e_j = 6, $s = 10^7$ (S/m), K = 0.95, y = 45°, and N = 8. If as above we assume the frequency f = 1 GHz, then $Z_t(s) \approx 0 + j4.9$ and $\Omega_t(s) \approx -j7(10)^6$. Z_t has a positive imaginary part indicating that coupling for this braided cable will be primarily inductive. Although the impedance is low, long runs of cable could mean that some voltage would appear at the cable end. The charge transfer frequency is well below the operating frequency and will not contribute significantly.

An accurate estimate of cable coupling would involve accounting for the geometry of a specific station (length of cable, nearby metallic structures), the cable parameters, the specifics of the incident field, and any breeches in the cable shield integrity or imperfect connections. However, based on the transfer quantities for tubular and braided cable it is expected that a good quality cable should not allow significant voltages to appear internally.

Table B1. The Function $g[(1-K)^{3/2}, y]$ for Some Typical Values

	$(1-K)^{3/2}$				
y	0.01	0.02	0.03	0.04	0.05
	(x 10^{-2})				
5°	0.539	1.091	1.657	2.236	2.829
10°	0.555	1.117	1.686	2.261	2.844
15°	0.584	1.173	1.767	2.366	2.969
20°	0.621	1.246	1.874	2.507	3.143
25°	0.667	1.337	2.010	2.687	3.368
30°	0.727	1.457	2.190	2.928	3.668
35°	0.807	1.618	2.433	3.253	4.076
40°	0.910	1.825	2.745	3.671	4.603
45°	1.045	1.098	3.158	4.226	5.303

Table B2. The Function $h[(1-K)^{3/2} f_d, y]$ for Some Typical Values

	$(1-K)^{3/2} f_d$				
y	0.01	0.02	0.03	0.04	0.05
	(x 10^{-2})				
5°	0.521	1.036	1.545	2.049	2.547
10°	0.502	1.001	1.496	1.987	2.475
15°	0.491	0.987	1.463	1.944	2.423
20°	0.480	0.956	1.431	1.902	2.371
25°	0.471	0.939	1.404	1.866	2.326
30°	0.463	0.922	1.379	1.834	2.285
35°	0.458	0.912	1.364	1.813	2.259
40°	0.455	0.906	1.355	1.801	2.244
45°	0.454	0.904	1.352	1.796	2.238